

Earth Sciences 089G
MIDTERM EXAMINATION MARKING KEY

Part 1. Multiple Choice Questions (Answer All)

Answer the following ten questions by circling the correct or most reasonable response on this sheet (10 marks total).

1. The outermost layer of Earth's geosphere is known as:
 - a) The hydrosphere
 - b) The aesthenosphere
 - c) The exosphere
 - d) The crust**
 - e) The ozone layer

2. Zinc, an element, has an atomic number of 30 and an atomic weight of 65.38. This means it must have:
 - a) 30 electrons, 35 protons, 30 neutrons
 - b) 35 electrons, 35 protons, 38 neutrons
 - c) 38 electrons, 38 protons, 35 neutrons
 - d) 38 electrons, 38 protons, 30 neutrons
 - e) 30 electrons, 30 protons, 35 neutrons**

3. Migmatites are "mixed rocks" which contain features of both:
 - a) Pyroclastic and sedimentary rocks
 - b) Plutonic and regional metamorphic rocks**
 - c) Contact metamorphic and diagenetic rocks
 - d) Regional metamorphic and igneous extrusive rocks
 - e) Chemical sedimentary and siliciclastic rocks

4. The primary mineral constituents of rocks of mafic and ultramafic (more mafic than mafic) composition necessarily contain the following elements.
 - a) magnesium, silicon, aluminum, oxygen
 - b) iron, aluminum, silicon, oxygen
 - c) silicon, oxygen, iron, manganese
 - d) oxygen, magnesium, silicon, iron**
 - e) aluminum, magnesium, iron, oxygen

5. Consolidated sediment preserving an impression of the outer surface of an ancient organism's remains is known as:
 - a) a trace fossil
 - b) an external cast
 - c) an external mould**
 - d) a coprolite
 - e) a steinkern

6. A sedimentary rock layer A is underlain by a flow basalt layer dated at 255 Ma. Layer A, a quartz-cemented sandstone, lacks fossils which allow it to be dated, however, similar sandstone strata underlying the flow basalt contain fossils of mammal-like reptiles suggestive of a mid to Late Permian (late Paleozoic) age. Layer A is directly overlain by

poorly consolidated sandstones which contain dinosaur fossils suggestive of Late Cretaceous (late Mesozoic) age. What can we infer about the age of Layer A?

- a) Layer A is older than 255 Ma
- b) Layer A is of Cretaceous age
- c) Layer A is of Late Permian-Triassic age
- d) Layer A is between 255 Ma and 65 Ma old**
- e) The age of Layer A can not be determined

7. Fossils may be found in an unaltered state in:

- a) Limestones
- b) Shales
- c) Amber
- d) Cherts
- e) All of the above**

8. Analysis of a rock sample selected for dating using radiometric techniques revealed that the concentration of the daughter isotope (for the isotope system used) was nearly eight times greater than the concentration of the parent isotope. The parent isotope is known to decay to the daughter isotope with a half-life of approximately 0.5 billion years. This suggests that the sample is at least:

- a) 500 million years old
- b) 1 billion years old
- c) 1.5 billion years old**
- d) 2 billion years old
- e) 3 billion years old

9. An igneous rock consisting of the minerals orthoclase (potassium feldspar), quartz, muscovite (mica), hornblende (amphibole), biotite (mica) and plagioclase (in that order or relative abundance) is likely, upon significant physical and chemical weathering, to produce sediment containing:

- a) clay minerals, quartz and muscovite**
- b) clay minerals, hornblende and iron oxide/hydroxide minerals
- c) quartz, clay and ferromagnesian minerals
- d) plagioclase, orthoclase and clay minerals
- e) orthoclase, quartz and muscovite

10. The process by which sediment becomes a sedimentary rock is known as:

- a) petrification
- b) carbonization
- c) compaction
- d) lithification**
- e) diagenesis

Part 2. Short Answer Questions Part A (Complete two of the three tables)

In each space provided in the right-hand column of the tables below, indicate the most appropriate term which corresponds to the item of significance in the left-hand column. You will note that each of the three tables has a common theme. Select and complete two of the three tables (10 marks total).

Significance	Corresponding term
A red gem-quality variety of corundum.	Ruby
A variant of the step cut used primarily for beryl gems.	Emerald cut Emerald (1/2)
A precious gem commonly presented in brilliant cut with four planes of cleavage.	Diamond
Pyrope is a characteristically red variety of this mineral.	Garnet
Resistance of a gem to fracture, cleavage, bending, crushing etc.	Tenacity Durability (1/2) Hardness (0)

Significance	Corresponding term
Minerals with the same composition but different crystal forms.	Polymorphs
The product of stress-induced orientation of mineral grains in regional metamorphic rocks.	Foliation
Process primarily responsible for the destruction of original rock textures during metamorphism.	Recrystallization
Local zone of alteration of country rock in close proximity to a magma chamber/intrusion.	Aureole, metamorphic halo, metamorphic aureole
Type of plate boundary with which regional metamorphism is most commonly associated.	Convergent plate boundary, Destructive plate boundary. Subduction zone (1/2)

Significance	Corresponding term
The flow of material as a result of temperature and/or density variations in fluids.	Convection
Plate tectonic process or setting primarily associated with dehydration melting.	Subduction, Subduction zone
A variety of tectonic boundary lacking significant associated volcanism.	Transform plate boundary, Strike-slip boundary
Tectonic force thought to account for most plate motion.	Slab pull Ridge push (0), Convection (0)
Name of the Supercontinent which formed near the end of the Palaeozoic Era.	Pangea Rodinia (0)

Part 3. Short Answer Questions Part B (Answer All)

Provide answers to fill in the blanks in the following sentences. The number of marks assigned for each answer is provided in brackets following the blanks (20 marks total).

1. The fossil myth primarily associated with St. Hilda of Whitby, England relates to the remains of organisms of the Class Cephlopoda _____ (1), also known locally as “_____”(1).

A)Cephalopoda, B) Snakestones

2. Two evaporitic rocks used extensively by the Ancient Romans were _____ (1), and _____ (1).

Rock Salt and Rock Gypsum (Alabaster); Halite/salt (1/2), Gypsum (1/2), Travertine (1/2), Limestone (0), Marble (0)

3. Lines on a topographic map that join points of equal elevation are known as _____ (1).

Contours/Contour lines

4. The “Shells of the Earth” which bound the asthenosphere vertically are known as the _____ (1) and the _____ (1).

Mesosphere (middle Mantle) and lithosphere; crust (0)

5. The high conductivity, malleability and ductility of metals relates primarily to _____ (2).

Metallic bonding or mobile valence electrons (not fixed in orbit around one nucleus) or something similar.

6. Continental lithosphere floats higher on the aesthenosphere than does oceanic lithosphere as a result of the _____ (2) and _____ (2) of continental lithosphere.

Greater thickness and lower density; thickness (1), density (1)

7. Three-armed clefts in the Earth’s crust which may develop further to produce new ocean basins are known as _____ (1).

Triple (point) junctions (incipient rift valleys)

8. Chalk is an example of a _____ (1) sedimentary rock.

Biogenic/Biochemical; Bioclastic (1/2), Carbonate (1/2), Fossiliferous (0)

9. A carbonate rock formed as a result of the dissolution and reprecipitation of calcite by groundwater, and noted for its characteristic banding is called _____ (1).

Travertine/Flowstone; Limestone (0)

10. Trace fossils which are highly useful in understanding the diets of the ancient organisms which produced them are known as _____ (1).

Coprolites; Fossil dung (1/2)

11. An igneous rock containing evidence of two or more stages of magmatic cooling is said to have a _____ (1) texture.

Porphyritic; with phenocrysts (1/2)

12. Pumice is a volcanic _____ (1) which typically contains numerous pore spaces known as _____ (1).

A) Glass, B) Vesicles

Part 4. Short Essays (Answer two of the following)

Select two of the following questions and prepare short essay responses using the examination booklet provided. Your answers should be written in complete sentences and be as detailed as possible, including definitions of relevant general concepts and other basic information, all the while dealing directly with what the questions ask. You may use labelled diagrams where appropriate to convey your ideas. Each question has a value of 15 marks (30 marks total).

1. Explain the concept of a “stellar habitable zone” and the premises (i.e. reasoning) behind it. Also explain, in theoretical terms, why this concept may be highly oversimplistic in terms of predicting where conditions conducive for life may occur within a solar system.

Allot marks (as indicated in brackets) for the following points. Note: In this scheme, it is possible that the students' answers may be worth more than 15 marks (in all cases), but 15 is the maximum number of points that will be awarded.

Definition of stellar habitable zone as region within a solar system (1) within which it is believed that life is capable of forming (1).

Location of zone depends upon distance from star (1) and type of star (1).

Life as we know it occurs only within planetary atmospheres (1), and requires the presence of at least minimal quantities of liquid water (1) in the crust or suspended in the atmosphere.

Liquid water only exists within a limited range of temperature (and pressure) conditions (1), and consequently, where predominant conditions are outside this range, life is unlikely to exist (1).

There are also more limited temperature (and pressure) ranges within which complex organic molecules and their building blocks (e.g. amino acids, proteins, DNA, RNA) will remain intact (1) and in which chemical reactions necessary for life will proceed (1).

Concept is oversimplistic because it assumes life elsewhere would be based on same elements (1) and preconditions as life on Earth (terracentric concept) (2), and that it must occur on terrestrial planets (1), which due to density of materials (1) are typically found within the inner solar system (1)

Concept is entirely conjectural. No adequate empirical evidence exists to support it (1).

Life may not be confined to planetary atmospheres (1). Life has been interpreted to be possible occur outside the “habitable zone” (Mars, Earth Venus) of our Solar System (e.g. moons of gas giants) (1).

Many students discussed Mars and Venus and what would happen to Earth if it were moved to their orbits, to illustrate the importance of the distance of planets from the sun in the concept of stellar habitable zones. This is not really what I was after but for these, allot points as follows.

If Earth were to move to the orbit of Mars, the decrease in incoming solar energy would cool the oceans (1/2), increase the size of the polar caps (1/2) and lead to less water vapour (a greenhouse gas) in the atmosphere (1/2).

Heat retention of the planet would decrease (1/2), thus reducing the temperature further, most likely below the threshold of tolerance for most multicellular organisms (1). In the extreme, the Earth would probably be covered with ice (1/2).

If Earth were to occupy the orbit of Venus, the increased solar radiation would raise the average temperature of the planet (1/2).

Raising global temperature would put more water vapour into the atmosphere (1/2) and, through the greenhouse effect, make the temperature even higher (1/2).

At extremely high temperatures, photosynthesizing organisms could not survive (1), leading to the accumulation of volcano-sourced carbon dioxide (1/2) in the atmosphere, and a further increase in temperature (1/2).

The planet’s surface would be dry, hot and barren and generally unsuitable for Earth-type life (1/2).

2. Describe the textural and compositional differences between the following igneous rock types: Granite, Gabbro, Basalt, Rhyolite. Explain how the rate and state of magmatic cooling contributes to the formation of these different igneous lithologies with reference to their environments of formation and Bowen’s Reaction Series.

Granite: Felsic (1), phaneritic/plutonic/intrusive (1) igneous rock

Gabbro: Mafic (1), phaneritic/plutonic/intrusive (1) igneous rock

Basalt: Mafic (1), aphanitic/volcanic/extrusive (1) igneous rock

Rhyolite: Felsic (1), aphanitic/volcanic/extrusive (1) igneous rock

The students should have noted that Granite and Rhyolite were basically compositionally equivalent (1) and Gabbro and Basalt were also compositionally equivalent (1).

The differences between Granite and Rhyolite and Gabbro and Basalt relate to differences in the rate and environment of cooling. Granite and Gabbro cooled slowly beneath the surface of the earth in igneous intrusions/plutons (1), consequently allowing time for the formation of large (macroscopic) mineral crystals (1).

Rhyolite and basalt cooled relatively quickly on/at the surface of the earth (1); consequently, there was not sufficient time for the formation of large (macroscopic) crystals (1) but microscopic mineral crystals are present (1).

They also needed to discuss the compositional differences between Granite-Rhyolite and Gabbro-Basalt. Here they had to make reference to Bowen's Reaction Series and the state of magmatic cooling at which mafic minerals (producing Gabbro-Basalt) and Felsic minerals (producing Granite-Rhyolite) are crystallized.

Mafic rocks (Gabbro-Basalt) predominantly contain ferromagnesian minerals (2) (olivine, pyroxene and Ca plag.), which crystallize at higher magma temperatures (1) and therefore solidify earlier in the magma cooling process (1).

Felsic rocks (Granite-Rhyolite) predominantly contain felsic minerals (quartz, K feldspar, micas, Na plag.) (2), which crystallize at lower magma temperatures (1), and therefore, at later phases of magma cooling (1).

3. Describe the major textural and mineralogical changes that occur as a shale is transformed, at increasingly higher metamorphic grades, into gneiss.

Shale is made of up predominantly by clay minerals (1)

As shale is metamorphosed at higher grades, it changes into the following rocks: Shale → Slate → Phyllite → Schist → Gneiss (4 marks for indicating series in some way)

Transformation involves textural changes (1) as well as mineralogical changes (1).

Mineral changes relate to the changing stability conditions at higher T and P (1).

Shale: Mineral crystals not visible (clay particles) (1), fissile (1), but lacks any foliation (1); a sedimentary rock (not metamorphic) (1). May contain unaltered fossils (1).

Slate: Microcrystalline (grains not visible to naked eye) (1), well-foliated and fissile (breaks into thin plates) (1). Fossils and other primary features may be preserved (1), fossils generally stretched or otherwise altered (1). Lustre, dull, to satin-like on cleavage surfaces (1/2). Clays still present (1) but many have transformed to micas (1) and Chlorite (1). Some carbon/organics transformed to graphite (1)

Phyllite: Very finely crystalline (grains just visible at 10X magnification) (1) and well foliated (1). Somewhat fissile (1). Clays still present (1), but continued growth of muscovite (mica) (1) and chlorite (1) and graphite (1). Lustre satin-like, usually somewhat glossy (1/2), due to growth of platy minerals, particularly muscovite (1/2).

Schist: Medium to coarsely crystalline (1) and well-foliated (flaky) (1) though not truly fissile (1). A diversity of minerals may be present (1), however platy minerals (micas) predominate over granular minerals (1). Clays largely gone (1). Typically highly lustrous (1/2) due to high content of macroscopic mica crystals (1/2).

Gneiss: Texturally and mineralogically similar to Schist, though granular minerals are more abundant than platy minerals (1). Micas and chlorite (platy minerals) typically occur in small quantities (1). Granular minerals such as K feldspars (1), quartz (1) and amphiboles (hornblende) (1) are most common.

4. The ancient mythological creature, the Griffin, was believed to have had a nest made of gold. Explain, in detail, the possible scientific explanation for this association.

The Griffin, one of the oldest mythical creatures, has existed for at least 5,000 years in human culture and has been a symbol in many cultures etc. (1). A maximum of one mark is to be awarded for telling us about the cultural significance of Griffins or the Griffin myth. If they went into detail about this, they were wasting their time.

The mythical Griffin was a composite creature (1), having the body of a lion (1) and the head and wings of an eagle (complete with a beak and talons on the forelimbs) (1).

The Griffin is said to have laid stone (agate) eggs (1) similar in size to those laid by ostriches. Agates are typically found as elongate nodules (1) with a prominent outer “crust” which might resemble an egg shell (1).

According to (Greek) legend, the Griffin’s nests (where eggs were found) were made of gold, a substance that the Griffin fiercely guarded (1) along with its eggs.

The idea of the Griffin probably originated in central Asia (probably in the Gobi desert region) (1). They need to indicate “Gobi Desert” to get full marks here.

Gobi Desert is known for its well-preserved dinosaur fossils (1). One of the most common types of dinosaur found is the Cretaceous (1) herbivorous dinosaur Protoceratops (1).

Protoceratops features: Compact skull with a strong beak (1) (used for snipping vegetation). The frill around the back of the skull is less commonly preserved intact than the rest of the skull (1).

A squat body with a long tail (1) and four legs (quadrupedal) (1). Noted similarity to a lion on the basis of these features (1)

Long shoulder blades (which could be misinterpreted as the bases of wings) (1).

Association with *Oviraptor* --as suggested by nests containing unhatched *Oviraptor* embryos (1).

One such nest preserves the skeleton of an adult *Oviraptor* fossilized in the act of protecting its nest (1).

***Oviraptor* more bird-like than *Protoceratops* (1), with beak-like snout (1) and a head crest (1); additionally it had forelimbs that bore talons (1), as well as a thinner tail (1). *Oviraptor* may fit Griffin myth better than *Protoceratops* (1).**

Oviraptor, bipedal (walked on two long bird-like back legs) (1) and had relatively light forelimbs (1). As typically conceived, the back legs of the Griffin were suggestive of quadrupeds (1). Oviraptor is not a perfect match (Protoceratops remains a contender) (1).

Possibility: The Griffin is a composite of two dinosaur species/genera (Protoceratops and Oviraptor) (1).

The Gobi Desert is known to contain extensive deposits of (aeolian) placer gold (1).

Definition of placer gold as gold that has been eroded and transported from its original/primary source by water and/or wind (1).

Some placer gold deposits in the Gobi Desert are known to be of the same general age (Late Cretaceous) as the dinosaur fossils (1).

Consequently, it is likely that particles of gold were being scattered across the desert by the prevailing winds and sand storms at the time (1).

The dinosaur nests (excavated as shallow depressions) are interpreted to have been made in low areas between vegetation-stabilized sand dunes (1).

The excellent preservation of many of the nests may be due to rapid burial as a result of sand dune slumping (1), especially during sand storms.

These depressions (troughs) in the sand dune fields are likely to have acted as gravity traps for detrital gold particles pushed along by the wind (1).

Due to their high specific gravity of gold (1), only the smallest gold particles would have been easily carried in suspension from the top of one dune to another (1).

Consequently, the sediments in these troughs would be enriched in heavier mineral components, including gold as most of these mineral grains would have fallen into the troughs (1).

Dinosaur nests at the bottom of the troughs are likely to have provided a barrier or baffle (1) for further movement of gold and therefore gold would have been concentrated there.

Early gold prospectors may have actively sought out fossil dinosaur nests with the knowledge that they were commonly associated with local concentrations of placer gold (1).

And thus the Griffin myth may have begun, or been modified resulting in the association of gold with Griffin nests

5. Explain why disconformities which lack evidence of significant erosion, might be the most difficult unconformities to discern with reference to the other unconformity types. In your answer, you will be expected to define the main unconformity types and contrast their key characteristics.

Two marks for defining unconformity: A geological/stratigraphic surface separating older from younger rocks and representing a significant gap in the geological record (2). Deduct ½ marks for each of the underlined concepts not included in the definition.

The three main types of unconformities are: nonconformities (1), angular unconformities (1), and disconformities (1).

Nonconformity: an unconformity that separates underlying (regional) metamorphic or (plutonic) igneous rocks (1) from overlying horizontal sedimentary strata (1; ½ if they don't indicate horizontal). These unconformities typically occur on a large scale and are usually characterized by a high degree of contrast between the underlying and overlying rocks (due to different major lithologies) (1). Significant erosion has occurred to permit this association (1).

Angular unconformity: an unconformity that separates underlying tilted (non-horizontal) rocks (sedimentary) (1), from overlying horizontal sedimentary rocks (1; 0 if they don't indicate horizontal). Usually also easily placed as a result of significant difference in orientation of strata below and above (1). Significant erosion of tilted beds to produce flat surface (peneplain) on which overlying horizontal strata may be deposited (1).

Disconformity: an unconformity that separates underlying horizontal sedimentary rocks (1; 0 if they don't indicate horizontal), from overlying horizontal sedimentary rocks (1; 0 if they don't indicate horizontal).

No large-scale differentiation above and below unconformity on the basis of rock type (1) or stratal orientation (1).

In the absence of significant erosion it may be very difficult to discern the presence of an unconformity as the rocks above and below may be of the same general character (e.g. both sandstones) (1). Even, if lithologies above and below are different, that does not mean that there has been a break in deposition (1). Detection of unconformity may require close examination of fossil content (1) in an attempt to find missing biozones (1), or close examination of lithological or chemical characteristics of the rock (1) which may reveal other evidence of a break in deposition.

Consequently, other types of unconformities would be much easier (less work-intensive) to identify that a disconformity lacking evidence of significant erosion.

6. Explain why. Also explain why absolute dating has greater relevance for the division of the Precambrian time scale and the correlation of rocks of this age.

First they should have identified the meaning and time interval of the Phanerozoic Eon. Phanerozoic means “visible/apparent life” (1) and is the interval from 545 Ma to present (1).

Knowledge of the absolute age of rocks was unnecessary for the creation of the finely divided time scale for the Phanerozoic Eon, mainly due the abundance of fossils in rocks corresponding to this eon (1) as contrasted with the relative lack of fossils in earlier eons which were of biostratigraphic use (1).

They should have defined **biostratigraphy**: The science which involves correlation of sedimentary rocks on the basis of their fossil content. This may be useful on a continental, and even a global scale (2). Deduct ½ marks for each of the underlined concepts not included in the definition.

Fossil content of sedimentary rocks change through geological time (1) as a result of evolutionary modifications, extinctions etc. (1). Consequently, different intervals of geological time have different fossil biotas associated with them (1).

They may define the law of fossil succession which states that fossils occur in a consistent vertical order in sedimentary rocks all over the world (1).

Thus, the relative age of “slices” of time represented in rocks can be determined from the fossil content of rocks (1).

When sufficient knowledge of the stratigraphic ranges of various fossils is available, it may be possible to identify intervals of rock known as “Zones”(biostratigraphic zones) (1) which are usually defined by the ranges (1) or first appearances (1) of key fossil taxa.

Zones may then be grouped together to form “Stages”(1), Stages grouped into “Series” (1) and Series grouped into “Systems” (1).

Systems are bodies of rocks which correspond to “Periods” (1) of geological time recognizable all over the world (1), e.g. The Jurassic Period.

Thus, periods are not defined on the basis of the absolute age dates applied to them (1), but instead, are defined on the basis of the unique fossil content of the corresponding rocks (1).

Biostratigraphy has been, and continues to be, the primary means of identifying strata belonging to different systems (periods) (1).

Radiometric dating, therefore, has not been necessary (1) for the development of a usable and finely divided geological time scale for the Phanerozoic Eon but has added the interesting element of absolute time.

Absolute (radiometric) dating is of greater significance for the division of the Precambrian, mainly due to the fact that fossils are either rare in rocks of this age (1) or are not useful biostratigraphically to the same extent that they are in the Phanerozoic (1). Major time boundaries (e.g. Eon boundaries) have been selected somewhat arbitrarily on the basis of widely recognizable radiometric dates (1). Although these boundaries may correspond to world-wide geological events, the use of radiometric dates to define their boundaries is thought to be necessary due to the potential for high degree of uncertainty in the correlation (or time equivalence) of these events(1).

7. Explain, in detail, how the transformations depicted in the Rock Cycle are directly related to various plate tectonic processes with reference to the three main rock types.

Definition of the rock cycle as a graphical depiction of the three major rock types (sedimentary, metamorphic and igneous) (3; they must indicate the names of three major rock types to get full marks here), and the processes which allow one rock type to be transformed into another (1).

Any of the three rock classes can be changed into any of the other rock classes (1).

Sedimentary or metamorphic rock (or pre-existing igneous rock) may be transformed into new igneous rock through melting of the original rock (protolith) (1), and subsequent cooling and consolidation of the molten rock (magma) (1).

Plate tectonic relationship: Sedimentary and metamorphic rocks are melted at depth in subduction zones (1) and are assimilated into mantle magmas which may later rise into the crust and cool and consolidate to form new igneous rock (1).

Igneous or metamorphic rock (or pre-existing sedimentary rock) may be transformed into new sedimentary rock through uplift and erosion/weathering (physical, chemical) of the protolith (1), which produces sedimentary grains and ions (1), which are transported in suspension, or in solution (1) to the point of deposition of grains or precipitation (1), which results in the formation of new sediment. The sediment later lithifies (1) to form sedimentary rock.

Plate tectonic relationship: Igneous and metamorphic rocks are uplifted in mountain building events (orogenies) (1), and undergo extensive (subaerial) erosion (1) by wind, water etc., which produces sediment grains and ions in solution (1), which are transported downward and laterally by wind, water, glaciers etc. (1), to a point of deposition/precipitation at which new sedimentary rock is created (1).

Igneous or sedimentary rock (or pre-existing metamorphic rocks) may be transformed into new metamorphic rock through deep burial of the protolith (1) and associated heating (1) and/or compression (1) of the original rock, which produce solid state alterations (1) including textural (1) and mineralogical changes(1), associated with metamorphism/metamorphic rocks.

Plate tectonic relationship: Igneous and sedimentary rocks, upon deep burial or intense heating as a result of crustal thickening in mountain building (collisional events at convergent plate boundaries)(1), or igneous activity associated with tectonism (proximity to igneous intrusions—contact metamorphism) (1) can undergo the solid-state textural and mineralogical changes associated with regional metamorphic rocks (1) in the first case, and textural changes associated with contact metamorphism (primarily recrystallization)(1), in the second case.

8. Describe, in detail, the various lines of evidence for plate mobility which were known prior to the formal acceptance of the theory of Plate Tectonics in the 1960s.

Here they should note the contributions of **Alfred Wegener** (award 1 point for the mention of his name—only once), as well as the **theory of Continental Drift** (1), this being largely Wegener's discovery.

The jigsaw puzzle fit of continents suggested the former existence of a supercontinent (1); especially South America (east coast) and Africa (west coast) (1). Noted by Wegener in 1910 (1/2).

Definition of Supercontinent: a (composite) landmass consisting of several or all of the known continents (1).

Wegener in 1915 (1/2), noted that fossils of land organisms (1), of Permian-Triassic age (1) such as the reptiles Mesosaurus and Lystrosaurus (1 for mention of either or both of these) and the fern Glossopteris (1) were distributed over several continents (1). Mention of possible land bridges (1/2).

When continents were joined up as in jigsaw puzzle, Wegener showed that there was a connecting and continuous linkage of fossil occurrences across the continents (1).

Used as evidence for the existence of Pangea (1).

Wegener also brought forth strong evidence for the linkage and common formation of well-known mountain ranges on either side of the Atlantic Ocean (1), as well as continuity of coal deposits in South America and Africa (1).

Old mountains belts (e.g. Appalachians and Caledonides) (1 point for mention of either of these mountain belts) are now separated, but if the continents are fit together, these mountain chains form a continuous belt.

Later (1940s-early 1960s)

Symmetry of magnetic stripes (1) which document successive polarity reversals of Earth (1) on sea floor lateral to mid-ocean ridges (1)

Relation to formation of new oceanic crust: Symmetrical pattern of normal and reverse polarities on either side of a divergent boundary can only be explained if magnetic polarity fluctuates as new crust is continually being formed (1).

The linear arrangement and sequential development of volcanic island and seamounts (1) as produced by a single stationary magma plume (hot spot) (1).

The Hawaiian Islands and Emperor Seamount Chain (1 for mention of either or both of these) are prime examples of this.

The distance of volcanoes from this hotspot (currently near Hawaii) increases through time (1). Heights of hotspot volcanoes decrease with increasing distance (and time) from the point of active volcanism (due to cooling and sinking of lithospheric material) (1). The “kink” in Hawaiian-Emperor volcanic island/seamount chain, indicates change in the direction of plate movement (1).